Stock Annex: Sole (*Solea solea*) in Subarea 4 (North Sea)

Stock specific documentation of standard assessment procedures used by ICES.

Stock:	Sole
Working Group:	Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak (WGNSSK)
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A. General

A.1. Stock definition

The North Sea sole is defined to be a single stock in ICES Subarea 4. The stock assessment is done accordingly, assuming sole in the North Sea is a closed stock between regions of Subarea 4.a, b ,c. This approach was supported by a thorough population genetic analysis using neutral microsatellite markers and a mitochondrial marker by Cuveliers *et al*. (2012). This study showed genetic differences at a large scale, along a latitudinal gradient from the Skagerrak/Kattegat to the Bay of Biscay. At a smaller spatial scale within the North Sea however, the subpopulations seemed genetically homogeneous, probably due to a high level of gene flow and/or the high effective population size preventing strong effects of genetic drift. With respect to the temporal aspect, a remarkable high genetic stability was found from the 1950s up to present (Cuveliers *et al*., 2011).

A.2. Fishery

North Sea sole is taken mainly in a mixed flatfish fishery by beam trawlers in the southern and south-eastern North Sea (see Figure 1). Directed fisheries are also carried out with seines, gillnets, and twin trawls, and by beam trawlers in the central North Sea. The minimum mesh sizes enforced in these fisheries (80 mm in the mixed beam-trawl fishery) are chosen such that they correspond to the Minimum Landing Size for sole. Due to the minimum mesh size, large numbers of (undersized) plaice are discarded. Fleets exploiting North Sea sole have generally decreased in number of vessels in the last ten years. However, in some instances, reflagging vessels to other countries has partly compensated these reductions. Besides having reduced in number of vessels, the fleets have also shifted towards two categories of vessels: 2000 HP (the maximum engine power allowed) and 300 HP (the maximum engine power for vessels that are allowed to fish within the 12 mile coastal zone and the plaice box).

The first ten years of the millennium the days at sea regulations, high oil prices, and different patterns in the history of changes in the TACs of plaice and sole have led to a transfer of effort from the northern to the southern North Sea. Here, sole and juvenile plaice tend to be more abundant leading to an increase in discarding of small plaice. A change in efficiency of the commercial Dutch beam trawl fleet has been described by

Rijnsdorp *et al.* (2006). This change in efficiency is related to changes in targeting and the change in spatial distribution (Quirijns *et al.*, 2008; Poos *et al.*, 2010).

In more recent years the Dutch beam-trawl fleet has changed considerably. New gears were adopted, such as the sumwing, and the pulse trawl. These new gears probably have different gear selectivity (van Marlen *et al.*, 2014) compared to the traditional beam-trawl gears.

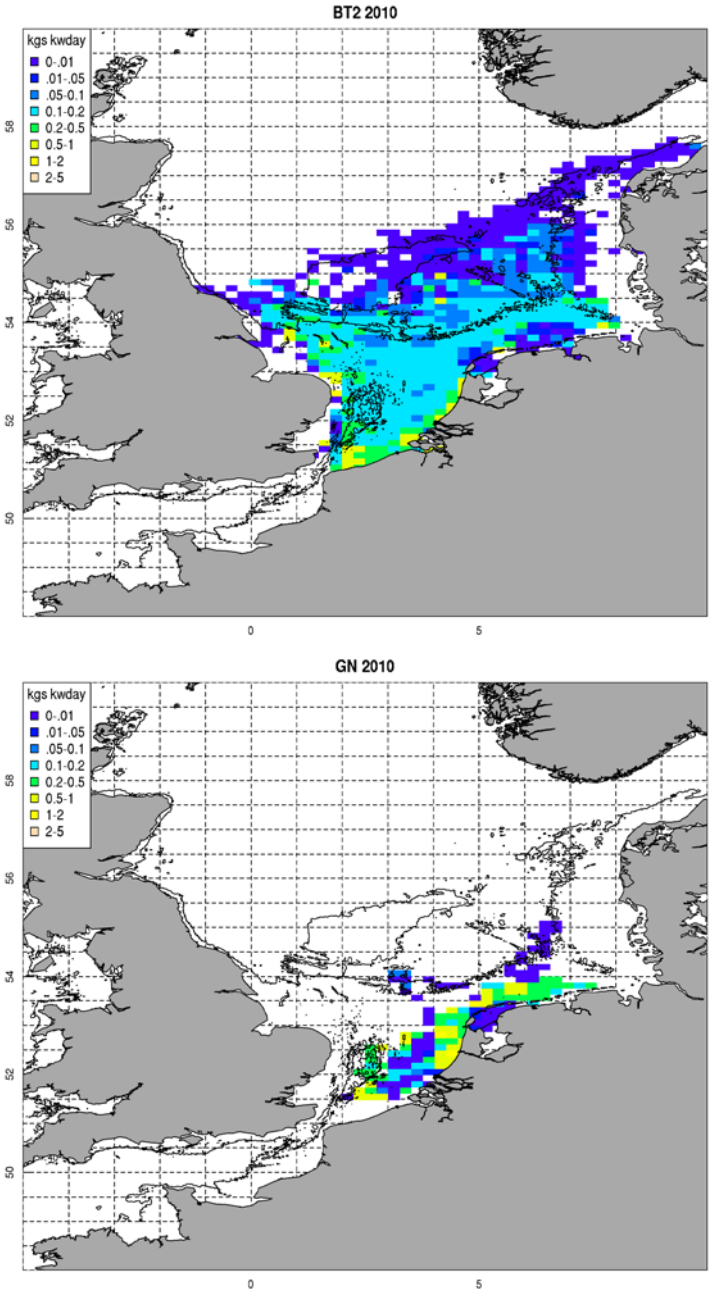

Figure 1. Landing rates (kgs kwday-1) in 2010 by Dutch flagged BT2 (beam trawlers working 80–89 mm mesh, top) and GN (gillnetters, bottom). Data are based on combining VMS and logbook data. 40 m depth contour also added.

Conservation schemes and technical conservation measures

Fishing effort has been restricted for demersal fleets in a number of EC regulations (EC Council Regulation No. 2056/2001, No. 51/2006, No. 41/2007 and No. 40/2008, annex IIa). For example, for 2007, Council Regulation (EC) No 41/2007 allocated different days at sea depending on gear, mesh size, and catch composition: Beam Trawls could fish between 123 and 143 days per year. Trawls or Danish seines could fish between 103 and 280 days per year. Gillnets was allowed to fish between 140 and 162 days per year. Trammel nets could fish between 140 and 205 days per year.

Several technical measures are applicable to the mixed fishery for flatfish species in the North Sea: mesh size regulations, minimum landing size, gear restrictions and a closed area (the plaice box).

Mesh size regulations for towed trawl gears require that vessels fishing North of 55°N (or 56°N east of 5°E, since January 2000) should have a minimum mesh size of 100 mm, while to the south of this limit, where the majority of the sole fishery takes place, an 80 mm mesh is allowed. In the fishery with fixed gears a minimum mesh size of 100 mm is required.

The minimum landing size of North Sea sole is 24 cm. The maximum aggregated beam length of beam trawlers is 24 m. In the 12 nautical mile zone and in the plaice box the maximum aggregated beam length is 9 m. A closed area has been in operation since 1989 (the plaice box). Since 1995 this area was closed in all quarters. The closed area applies to vessels using towed gears, but vessels smaller than 300 HP are exempted from the regulation.

A.3. Ecosystem aspects

Sole growth rates in relation to changes in environmental factors were analysed by Rijnsdorp *et al*. (2004). Based on market sampling data it was concluded that both length-at-age and condition factors of sole increased since the mid-1960s to a high point in the mid-1970s. Since the mid-1980s, length-at-age and conditions have been intermediate between the troughs (1960) and peaks (mid-1970s). Growth rates of the juvenile age groups were negatively affected by intra-specific competition. Length of 0-group fish in autumn showed a positive relationship with sea temperature in the 2nd and 3rd quarters, but for the older fish no temperature effect was detected. The overall pattern of the increase in growth and the later decline correlated with temporal patterns in eutrophication; in particular the discharge of dissolved phosphates from the Rhine. Trends in the stock indicators e.g. SSB and recruitment, did not coincide, however, with observed patterns in eutrophication.

In recent years no changes in the spatial distribution of juvenile and adult soles have been observed (Grift *et al*., 2004). The proportion of undersized sole (<24 cm) inside the Plaice Box did not change after its closure to large beamers and remained stable at a level of 60–70% (Grift *et al*., 2004). The different length groups of sole showed different patterns in abundance. Sole of around 5 cm showed a decrease in abundance from 2000 onwards, while groups of 10 and 15 cm were stable. The largest groups of sole showed a declining trend in abundance, which had already set in years before the closure.

Mollet *et al*. (2007) used the reaction norm approach to investigate the change in maturation in North Sea sole and showed that age and size at first maturity significantly shifted to younger ages and smaller sizes. These changes occurred from 1980 onwards. Size at 50% probability of maturation at-age 3 decreased from 29 to 25 cm.

B. Data

B.1. Commercial catch

Landings data by country and TACs are available since 1957. The Netherlands has the largest proportion of the landings, followed by Belgium. Discards data are only available since 2002, with the Netherlands, Belgium, Germany, and Denmark each starting their observation programs in a different year. The discards percentages observed in the Dutch discard sampling programme were much lower for sole (for 2002–2008, between 10–17% by weight) than for plaice. No significant trends in discard percentages have been observed since the start of the programme.

Age and sex compositions and mean weight at age in the landings have been available for different countries for different years. In the more recent years, age compositions and mean weight-at-age in the landings have been available on a quarterly basis from Denmark, France, Germany (sexes combined) and The Netherlands (by sex). Age compositions on an annual basis were available from Belgium (by sex). Overall, the samples are representative of around 85% of the total landings. For the final assessment, the age compositions are combined separately by sex on a quarterly basis and then raised to the annual international total. Alternatively, sex separated landings-at-age and weights-at age can be calculated from the data. Since the mid-1990s, annual sole catches have been dominated by single strong year classes (e.g. the 2005 year class).

B.2. Biological

Weight–at–age

Weights-at-age in the landings are measured weights from the various national market sampling programs. Weights-at-age in the stock are the 2nd quarter landings weights, as estimated by the Intercatch database computer program used for raising North Sea sole data. Over the entire time-series, weights were higher during the 1970s and 1980s compared to time periods before and after. Estimates of weights for older ages fluctuate more because of smaller samples sizes due to decreasing numbers of older fish in the stock and landings.

Natural mortality

Natural mortality has been assumed constant over all ages at 0.1 since the start of the assessment period (1957), except for 1963 where a value of 0.9 was used to take into account the effect of the severe winter (1962–1963; ICES, FWG 1979).

Maturity

The maturity ogive is based on market samples of females from observations in the sixties and seventies. Mollet *et al*. (2007) described the shift of the age at maturity towards younger ages. A knife-edged maturity-ogive is used, assuming no maturation at ages 1 and 2, and full maturation at age 3.

Surveys

There are five trawl surveys that could potentially be used as tuning indices for the assessment of North Sea sole.

- The BTS-ISIS (Beam Trawl Survey)
- The SNS (Sole Net Survey)
- The UK Corystes survey

- Belgium BTS survey
- German BTS survey

The BTS-ISIS (Beam Trawl Survey) is carried out in the southern and south-eastern North Sea in August and September using an 8 m beam trawl. The SNS (Sole Net Survey) is a coastal survey with a 6 m beam trawl carried out in the 3rd quarter. Data from 2003 and 2012 were omitted from the assessment because of changes in the survey in that year, or because not enough stations were sampled. In 2003 the SNS survey was carried out during the 2nd quarter and data from this year were omitted from the assessment. The research vessel survey time-series have been revised by WGBEAM (ICES, WGBEAM, 2009). WKFLAT 2010 decided to not use the UK Corystes survey because of lack of information on the raising procedure and spatial coverage of the UK Corystes series. WKNSEA 2015 decided not to use the German and Belgium BTS surveys. The German BTS survey was not used because it failed to detect cohort signals since 2010 and because the index was unavailable since 2012. The Belgian BTS survey was not included because it was only available since 2007 and because including it was found to increase the retrospective pattern in the assessment. WKFLATNSCS 2020 adopted an index of abundances that combines the Dutch (Isis and Tridens), Belgium and German BTS Q3 samples though a delta-lognormal GAM model.

B.3. Commercial lpue

There is one commercial fleet available that can be used as a tuning series for the stock assessment, being the Dutch beam-trawl fleet. This fleet takes more than 70% of the landings, and is relatively homogeneous in terms of size and engine power. The data from this commercial fleet can be estimated using two different methods. The first method uses the total landings, and creates the age distribution for these landings by segregating the total landings into market categories, with age distributions being known within market categories through market sampling. Effort for the Dutch commercial beam-trawl fleet is expressed as total HP effort days. Effort nearly doubled between 1978 and 1994 and has declined since 1996. Effort during 2008 was <40% of the maximum (1994) in the series. A decline of circa 25% was recorded in 2008 following the decommissioning that took place during 2008.

Alternatively, the data for the Dutch beam trawl fleet can be raised as described by (WGNSSK 2008, WD1). This allows reviewing the lpue trends in different areas of the North Sea. The data are based on various sources (WGNSSK 2008, WD1). There is a clear separation in lpue between areas, with the southern area producing a substantially higher lpue than the northern area. Average lpue of a standardized NL beam trawler (1471 kW) over the period 1999 to 2007 was 266 kg day-1, and the data have a significant ($P<0.01$) temporal trend of -6.1 kg day-1 year-1.

The beam-trawl fleet has changed gear use over the last ten years, switching from the traditional beam-trawl gear to wing-shaped gear and subsequently also to pulse fishing. In 2014, there was only very limited effort left with the traditional gear. As a result of the changes in the gear, the catchability has likely changed. Hence, WKNSEA 2015 decided not to use the lpue series in the assessment. From 2019, the fishery is moving back to the beam-trawl gear, as pulse fishing is being gradually banned and will not be allowed after June 2021.

C. Historical stock development

WKFLATNSCS 2020 decided that an AAP (Aarts and Poos, 2009) model was still appropriate for the assessment of this stock. The AAP method is a variety of statistical catch-at-age model that uses splines to estimate the selectivity patterns in the surveys and for the catch-at-age matrix. Spline smoothers are used to describe the F-at-age matrix, the catchabilities at-age of the tuning indices, and the discards fraction-at- age. The method allows incorporation of the incomplete time-series of discards consistently into the assessment.

There are three differences compared to the original model by Aarts and Poos (2009). 1) modelling of the F-at-age matrix by means of a tensor spline rather than using a full separability assumption. In the AAP model, the F-at-age matrix describing the F estimates for each year and age is built using a selectivity pattern over the ages (ranging between 0 and 1), an annually varying product of catchability and effort. Here, we describe the F-at-age matrix by using a design matrix for a tensor product smoother taken from the GAM function in R (Wood, 2006). The degree of smoothness depends on the dimensions of the bases for age and year. The design matrix is multiplied by the total number of parameters required to describe the tensor product smoother, being equal to the product of the bases for age and year. To ensure that the F-at-age matrix remains positive throughout the optimization, the tensor product smoother is exponentiated. 2) The proportion discarded at-age is described by a simple logistic function. 3) implementation of the maximum likelihood search in ADMB (Fournier *et al*., 2012) rather than in R.

The AAP model 1) is now build into a fully-compatible FLR package, 2) allows adding any number of tuning indices, 3) deals with missing values in any of the data sources, and 4) takes a control object with the structural model assumptions. These include: 1) The number of parameters used for the tensor spline (for ages and years separately), the age at which the "q-plateau"starts for the tuning indices, and the number of parameters used for description of the selectivity-at-age of the tuning indices.

Model used as a basis for advice

The North Sea sole advice is based on the AAP stock assessment. Settings for the final assessment are given below:

SETTING/DATA	VALUES/SOURCE
Catch-at-age	Landings (since 1957, ages 1–10) Discards (since 2002, ages 1–10)
Tuning indices	BTS-GAM 1985-assessment year, ages 1–10+ SNS 1970-assessment year, ages 1–6
Plus group	10
First tuning year	1970
Time-series weights	No taper
Catchability catches independent of ages stock size for age >=	9
Catchability surveys independent of ages for ages >=	8
Tensor spline for catchability-at-age both indices k value ages	6
Tensor spline for F-at-age: k value ages	8
Tensor spline for F-at-age: k value years	28

D. Short-term projection

The short-term projection is carried out in FLR using FLasher. Weight-at-age in the stock and weight-at-age in the catch are taken to be the mean of the last five years. The exploitation pattern is taken to be the mean value of the last five years. Population numbers-at-ages 2 and older are survivor estimates from the assessment model, unless there is consistent indication from the most recent recruitment surveys of a stronger or weaker year class. These indications should come from RCT3 analyses. Numbers at age 1 are either obtained from RCT3 (usually for age-1 abundance in the "intermediate" year) or are taken from the long-term geometric mean (usually for age-1 abundance in years after the "intermediate" year).

In the last few years, management options have been given for the assumption that F in the "intermediate" year is equal to the average estimate for F of the last three assessment years scaled to the last year's F. If this *status quo* F level led to catches higher than the agreed TAC, the F corresponding to the TAC in place for that year is applied instead.

E. Medium-term projections

Generally, no medium-term projections are done for this stock.

F. Long-term projections

Generally, no long-term projections are done for this stock.

G. Biological reference points

In 2016, ICES requested precautionary and limit reference points for all stocks. The WKFLATNSCS 2020 adopted a new set of reference points. These are the reference points used in the 2020 advice. More information is available in the WKFLATNSCS (2020) report.

The updated reference points and their technical bases are as follows.

Framework	Reference point	Value	Technical basis	Source
MSY approach	MSY Btrigger	42838 t	Default to value of Bpa.	ICES (2015b)
	FMSY	0.207	Median of stochastic MSY analysis, assuming a hockey-stick stock–recruit relationship.	ICES (2014)
Precautionary approach	Blim	30828 t	Breakpoint of segmented regression	ICES (2015b)
	Bpa	42838 t	Bpa = Blim × exp(1.645 σB), with σB = 0.20	ICES (2015b)
	Flim	0.42	The F that in equilibrium will maintain the stock above Blim with a 50% probability	ICES(2016a)
	Fpa	0.302	Fpa = Flim × exp(-1.645 σF), with σF = 0.20	ICES(2016a)
Management plan	FMGT	0.2	Stage two: Article 4.3 – FMSY	EU management plan (Council Regulation No. 676/2007)

Prior to 2020, reference points were as follows.

Reference points were revised at WKNSEA 2015, and then finalized by RGPA and ADGNS 2016.

	Type	Value	Technical basis
Precautionary approach	Blim	26 300 t	Breakpoint in segmented regression stock–recruitment relationship
	BPA	37 000 t	1.4 *Blim
FMSY	FMSY	0.2	Median of stochastic MSY analysis, assuming a hockey-stick stock–recruit relationship.
Targets	Fmgt	0.2	EU management plan

H. Other issues

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